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Bridging the gap between assessment and action: recommendations for the effective use of LCA in the building process

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Abstract. Environmental life cycle assessment (LCA) witnesses increasing popularity in the built environment. LCA stimulates among others an efficient use of natural resources and a reduction of carbon emissions through quantification of material and energy inputs and emissions in the building life cycle. Thereby, LCA aspires to contribute to SDG12 on ensuring sustainable consumption and production patterns. Despite high ambitions, the actual influence of LCA in construction projects is often modest. The mere application of LCA methodology in a building project is insufficient to produce a more environmentally friendly building. To better understand the practical conditions under which an LCA may induce change in a building project, we propose to analyse the use of LCA from a processual perspective. This paper presents a case study of a building product development project in which a processual perspective is applied on LCA. Using a longitudinal ethnographic methodology, key actors are followed through environmentally relevant episodes as the building project matures. A progressive LCA quantifies the potential environmental impact of the project as it progresses through different stages of the building process. Based on the learnings from this study, recommendations are presented to support the effective use of LCA in sustainable building practices, and contribute to SDG12 on sustainable consumption and production patterns.

1. Introduction

Life cycle assessment (LCA) is a methodology used to assess the expected environmental impacts of products and services. In the case of buildings, LCA can identify where environmental problems lie with existing solutions, but also calculate potential improvements in the environmental performance of alternative design options. The holistic ambitions of LCA cover both different stages of the product life cycle as well as different environmental concerns. LCA can therefore be used to identify and support actions that address climate change as well as other environmental problem areas. With industrial ecology it shares the underlying ideal to combine an accurate description with an ambition to inspire action [1].

In a building context, one way for LCA to inspire action is by influencing building projects. The building project is a central organising principle in the building industry [2, 3]. It is in building projects that designs materialise and that many material and emission flows are created. For the time being, LCA is rarely applied during the planning and production of ordinary buildings [4]. One reason for this is the voluntary nature of LCA [5]. Also, a shortage of data, money, ability and time hinders the effective use of LCA in building [4, 6, 7]. A question that is typically neglected is whether the current use of LCA is well suited to the needs and possibilities of building projects.

Currently established LCA approaches have a strong preference for retrospectively analysing finished building designs [e.g. 8]. This approach benefits the accuracy of LCA results. The design has stabilised in its final form and the analyst has time to conduct the LCA analysis. However, in order to use LCA during a building project, the analyst is confronted with a design that changes as the project matures. In addition, the analyst faces stronger time constraints and data uncertainties. The temporal demands that a building project places on LCA are different from those placed on retrospective LCA and may hinder its effective use.

To better understand the practical conditions under which an LCA may induce change in a building project, we propose to analyse the use of LCA from a processual perspective. A processual perspective to building LCA focusses on what happens when LCA is used during a building project. In studies of construction management, a processual perspective is used regularly to explain change [9, 10]. To our knowledge, no studies exist that take a processual perspective to LCA in the building project. Closest identified studies combine an actor-oriented approach to life cycle management in building companies [11] and building LCA [12].

In this paper, we present a case study of a building product development project in which a processual perspective is applied on LCA. Based on the learnings from this study, recommendations are presented to support the effective use of LCA in sustainable building practices, and contribute to SDG12 on sustainable consumption and production patterns.

2. Towards a processual perspective on LCA

A chief concern with current LCA approaches is that they tend to overlook the temporal particularities that come with applying LCA in a building project. As mentioned, LCA is typically applied retrospectively on a finished building design [8]. This gives the LCA analyst time to collect the inventory data from the design and perform the analysis. Retrospective LCA studies may be instrumental in learning about the environmental performance of a building, and may indirectly lead to changes in future building design. They cannot, however, directly influence the building design and construction assessed. Retrospective LCA may assess accurately with the benefit of hindsight, but its knowledge comes too late to play a role in the particular building project that delivers the inventory data. While this weakness may be of little concern in mass production industries with repetitive production methods, it does matter in building projects that are more unique. The constellation of actors and building designs solutions changes between building projects [5, 13]. With each new building project, comes a (somewhat) different group of actors and a different design, degrading the carefully crafted retrospective LCA to 'outside information'.

One way to improve the use of retrospective LCA is to reduce the time needed for analysis by relying on BIM and automated scripts. In this way, Hollberg *et al* analyse an evolution of a building throughout 30 versions of a design [14]. The promise of the described approach is to provide environmental information at repeated intervals in the design process. A weakness of this BIM-inspired approach is that it builds on a high-quality digital information flow. While this could be a goal to aspire to, the reality of most building projects is different. Inventory data available in building projects tends to be structured heterogeneously and more sparsely available than hoped for. This affects negatively the opportunities in which BIM-LCA can contribute. While BIM may be a concept that can inspire a rationalisation of the building process, for now many building projects do not follow its path.

Another established approach in LCA is to look forward in the future. In prospective LCA, emerging technologies are assessed using scenario's in which they develop into a mature state. The aim of prospective LCA is to create knowledge in an early phase of development, where the opportunities to make changes are typically larger [15]. Prospective LCA studies give up the benefit of hindsight that retrospective LCA studies have. In return, prospective LCA gains the opportunity to inspire change and shape the future. Like retrospective LCA, prospective LCA studies are comfortable in the time allotted for analysis, as the future is still far away. Prospective LCA is used primarily to study technology level

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strategic decisions [15, 16]. In a building context, this makes prospective LCA relevant for strategic questions related to energy efficiency and energy supply [17] or even the development of novel materials and technologies. However, few building projects aim to contribute directly to strategic technology development, and even if they do, their individual contributions are typically negligible. This limits the use of prospective LCA for building projects.

While much can be learned from retrospective and prospective LCA, as well as a BIM-inspired rationalisation of the building process, it is also important to recognise that these approaches are not well suited to the logics of the building project. Given the special importance of the building project in the planning, design and construction of new buildings, one may wonder whether LCA would not inspire more changes in building, if it fits better with the dominant organisational logics of the construction industry.

3. Research method

This paper builds on an ongoing longitudinal research on the integration of LCA in the planning, design and construction of residential buildings. In this research, a residential building product development project is studied through environmentally relevant episodes as the building design matures. The case study exists of a building product development project in a large Swedish construction company. The project is situated in a product development group within the organisation.

Using an ethnographic method, a detailed description is created of what happens in the project throughout its subsequent stages. The data collection for this article took place between November 2018 and May 2019 and was conducted by the main author of the article. During this time, the program design and system design were conducted. The qualitative data consist of participant observations at project meetings (16 days, >100h), semi-structured interviews with project members (10) and project documentation (>500). Based on this data, a process description of the building project is made.

In addition, LCA is used to quantify the potential environmental impacts of the design as it progresses through different stages of the building project. Table 1 gives an overview methodologically relevant information for LCA studies conducted and used in the context of the building. The LCA calculations in stage I, III and IV were conducted by the main author of the article based on the knowledge available to the members of the project team at that particular time in the design process. For this reason, the analysis in stage I is necessarily based on previously completed designs in the company portfolio. Analysis III is based on a shoebox model of the building's design at the end of the program design phase. The shoebox model consists of the material layers of slabs, bearing- and non-bearing walls, which is multiplied by the area of each element. Analysis VI follows the data used in the cost estimation during the system design phase. An outlier is analysis II, which is an external study that was relevant in the project's program phase. Aside from a different building design, analysis II is also based on different emission data.

What becomes clear from Table 1 is that many inputs in the LCA analyses differ between the stages (I-VI). This is a logical consequence when adopting a processual perspective to LCA. Placing the building project and the emerging building design central in the analysis, one loses some of the consistency that LCA studies typically aim for. What is gained is a processual description of environmentally relevant episodes in the building design (#1-17), and the LCA-based environmental information available to the project team during each of the building stages.

Table 1. Description of LCA methodological choices in the LCAs of relevant environmental episodes

Building stage	Planning	Program		System
Analysis cohort	I	II	III	VI
Source of LCA knowledge	Own LCA calculation	External LCA study [8]	Own LCA calculation	Own LCA calculation
Building design	Old designs in portfolio	External design	New design	New design
Building design maturity	Finished design	Finished design	Program design	System design
Heated floor area (HFA)	924 m^2 2478 m^2	2198 m^2	1041 m^2	1078 m^2
Expected energy use (heat, water, build el)	67 kWh / m^2 y 64 kWh / m^2 y	53 kWh / m^2 y	74 kWh / m^2 y	63 kWh / m^2 y
Climate	Dfb	Dfb	Dfb	Dfb
Information modules (EN 15978)	A1-3	A1-3	A1-3	A1-3
LCI bill of quantities	Data used for cost estimation	Data used for cost estimation	Shoebox model m2 element	Data used for cost estimation
LCI emission data	EcoInvent v3.3 alloc. def.	IVL env. database	EcoInvent v3.3 alloc. def.	EcoInvent v3.3 alloc. def.
LCIA categories	GWP	GWP	GWP	GWP
LCIA method	ReCiPe 2016 midpoint (H)	Unsure	ReCiPe 2016 midpoint (H)	ReCiPe 2016 midpoint (H)
Episode	(#1-2)	(#5-9)	(#10-15)	(#16-17)

4. Environmentally relevant episodes

4.1. Early planning phase

Concerns about the sales volumes and unsustainable technical solutions of an existing building product forms a breeding ground for ideas to develop a new building product (#1). Especially compared to a competing product (#2), the group's own product is said to perform poorly. An initial goal is to develop a more sustainable building product. With encouragement from the top management of the company, this goal initially translates into an ambition to develop a new residential building with a wooden load-bearing system. The envisioned project leader takes on board an inhouse structural engineer and visits over the course of a year numerous wood-based construction seminars and trade-conferences to learn about the different possibilities that wood-based construction has to offer. While the potential reduction in CO_2-e is still somewhat vague, the two members of the project team are excited about the possible sustainability improvements that a wooden building could bring (#3).

During the planning stage, a personnel change in top management takes place. From the new top management team comes an alternative ambition to try to improve the currently used concrete-based construction solutions. This goal change is interpreted by the project team as a more conservative choice, and the project team expects to adjust their sustainability ambitions accordingly (#4). Expectations about the potential reduction of CO_2-e emissions to be achieved are still vague but go up to 30-50%, compared to the company's standard solution. An architect is hired to sketch a rough form of the building based on a few basic functional requirements. A project group of around 20 people is put together. It comprises of members of the product development unit and different inhouse and external consultants. During the upcoming design stages, the project group will meet on a weekly basis to develop the new building project.

So, it can be said that four (types of) designs were discussed during this stage – their LCA impact levels are shown in figure 1a.

4.2. Programmatic design
In the beginning of the program design stage the form of the building is largely formalised. The shape of the building differs somewhat from the original building product (#1) whereas it is not at all comparable to the competing product (#2). The sustainability goal is to reduce the CO_2-e emissions of the project with 30% compared to the design of the building as it would have been built using the standard solution.

An important reference point from an LCA perspective was a recently published study comparing the CO_2-e emissions of five different building systems for a multifamily residential building [8] (#5-9). While the study's building design differs from the project design, the types of building systems are taken under active consideration. They include three concrete-based building systems (#5-7) and two wood-based building systems (#8,9). From the external LCA study, it can be deduced that wood-based building systems would be probably needed to achieve the 30% reduction target.

In line with the preference of a reference group of local production units, and top management ambitions, the project leadership decides to hold on to the concrete-based path. In the final program design, a slimmed concrete load-bearing system is presented (#11-13), that can be compared to the standard solution (#10). Different combinations of elements produce somewhat different results, yet, possible maximum (#14) and a minimum (#15) impacts lie close to one another with this constellation of alternatives.

4.3. Systems design
During the systems design, the preferred alternative is worked out further. The goal remains to achieve a 30% reduction compared to a standard solution. During this stage, the project team works on the different systems of the building to develop a design that can be produced with little extra work. At the end of the systems design stage a new product is presented. Based on an initial cost calculation, a more detailed LCA of the final design was made (#17). To be able to learn how much reduction in CO_2-e the new design has been able to bolster, an alternative calculation was made as if the building was conducted with standard solutions (#16).

5. LCA results available during the project
LCA results for each environmentally relevant episode (#1-17) are presented in Figure 1. Figure 1a shows a large variety in kg CO_2-e emissions in the different analyses presented. These differences are partially due to differences in building design. Analyses I and II are from different building designs altogether and cannot serve as a basis for direct comparison with later designs. Analysis III comes from rudimentary design alternatives considered in the program stage. Analysis VI contains analyses of a more complete design from the system design stage. These design differences also translate into LCA modelling choices, introducing further uncertainty. For this reason, it is difficult to compare the absolute results, outside each of the four cohorts. It is also for this reason, that normalised results to a single baseline (figure 1b) are of little use as they do little to ease the differences.

Figure 1c presents the same results, but this time normalised to a baseline for each cohort of analyses. This representation shows less dramatic jumps between the different cohorts. Especially, the progress from III to VI is much less dramatic than in figure 1a and figure 1b.

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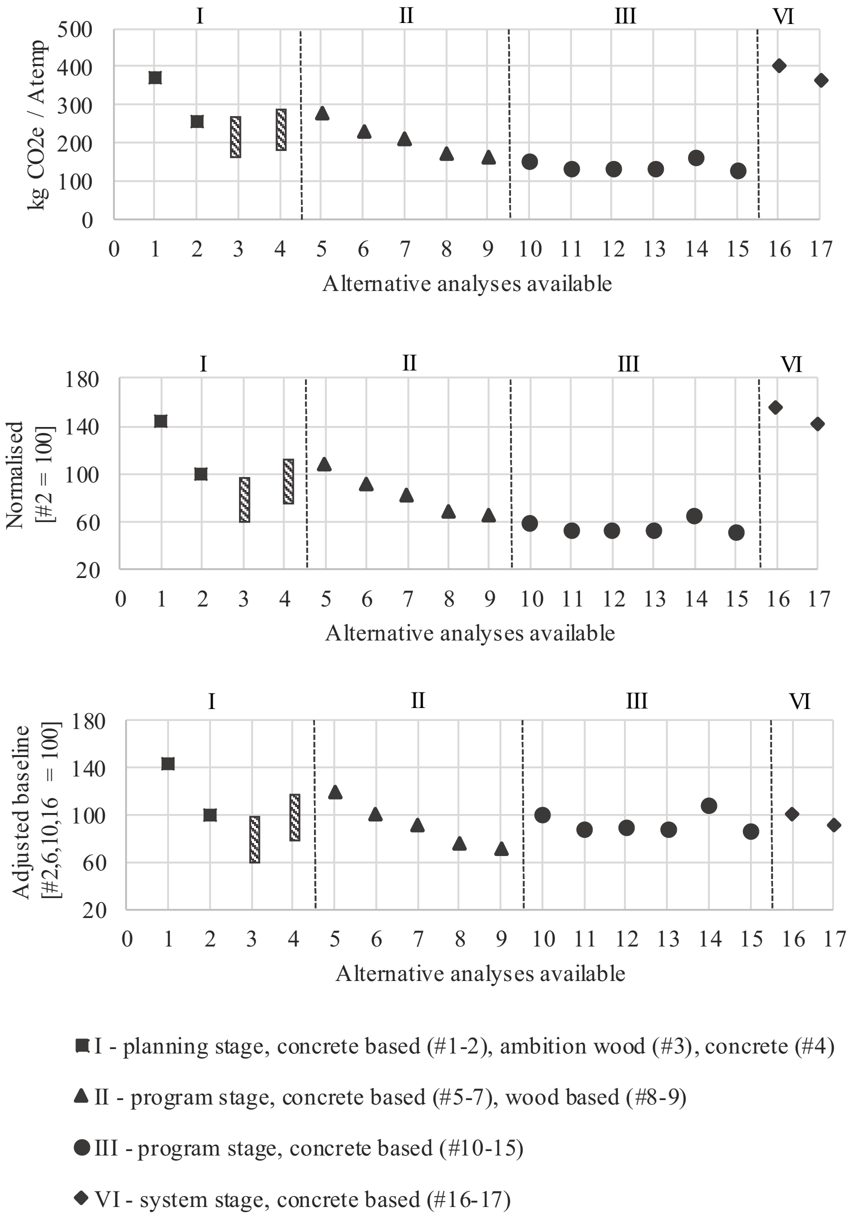
Figure 1. LCA results for alternative analyses of environmentally relevant episodes, based on heterogeneous data available during the project; 1a.) absolute results, 1b.) results normalised to a single baseline, 1c.) results normalised to a baseline in each cohort.

1a.) Absolute results

1b.) results normalised to a single base line (#2)

1c.) results normalised to a baseline in each cohort (#2, 6, 10, 16)



6. Recommendations for using LCA in the building project

The difficulty to compare LCA results between project stages I-VI presents a problem for the LCA analyst in the building project. The high absolute values for the final building design #17 may make it seem that the building project was not very successful in their environmental ambitions. Whether or not this statement holds truth, the comparison on which it is based is allusive. It is incorrect to compare design #17 to #1-2 (different design), #5-9 (different emission data), or #10-15 (less detailed inventory model). Only #16 is a legitimate comparison for building #17. However, at the same time, are #1-15 the only environmental information points available during the building project that can affect design #17. In order to connect with the project members and their activities, the results from #1-15 need to be useful as well.

The presented recommendation in figure 1c is to normalise the results for each cohort of analyses. In doing so, it becomes clear that the relative improvement of #17 in cohort VI is less than for the building systems presented under cohort II. This makes sense as cohort II includes a larger variety of building systems. Furthermore, it shows that the improvements in the systems design phase (VI) are more in line with those in the program design (III). This fits the general description of the project in which few changes were introduced during the system design stage. The use of multiple baselines may therefore be a way to make useful the LCA information available in (#1-15).

7. Conclusion

In 'science in action', Bruno Latour gives a by now classic account of the messiness that becomes visible when following scientists and engineers in their daily work [18]. In Latour's ethnographic descriptions uncertainty prevails and contextual factors intertwine with the content of the knowledge that is produced. Only afterwards, can context and content be separated, and emerges the retrospective clarity and certainty that people have come to expect from science and technology.

The lesson for LCA is as simple as it is fundamental. Existing building LCAs insufficiently consider the context in which buildings are made. The *building project* is a central organisational frame for understanding and changing the environmental impacts generated by the production of buildings. Using LCA in a building project context, one has to be prepared for a messier and more uncertain way of working. It involves working with more variety in design and data sources than LCA is traditionally used to. It also involves generating an understanding for the dynamics of the building project. These are aspects that are not well explored in building LCA.

With this paper, we attempt to make a small step towards a better understanding and use of LCA in the building project. By adopting a processual perspective, it becomes possible to see the evolution of the design and LCA knowledge over the course of a project. As the analysis shows, it is inevitable in this process to give up some of the certainty and clarity that LCA may have become accustomed to. We expect the gains to be worth the sacrifice. A better understanding of the building project will contribute to the ability of LCA to bridge the gap between assessment and action, and inspire actions that reduce the environment burden of the built environment. By looking at a more flexible baseline for comparison, we presented a possible way to regain some traction for LCA in the building project.

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